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Preface

As computers and communications technology advance, greater opportunities arise for intelligent mathematical computation. While computer algebra, automated deduction and mathematical publishing each have long and successful histories, we are now seeing increasing opportunities for synergy among them. The Conferences on Intelligent Computer Mathematics (CICM 2009) is a collection of co-located meetings, allowing researchers and practitioners active in these related areas to share recent results and identify the next challenges. The specific areas of the CICM conferences and workshops are described below, but the unifying theme is the computerized handling of mathematical knowledge.

The successful formalization of much of mathematics, as well as a better understanding of its internal structure, makes mathematical knowledge in many ways more tractable than general knowledge, as traditionally treated in artificial intelligence. Similarly, we can also expect the problem of effectively using mathematical knowledge in automated ways to be much more tractable. This is the goal of the work in the CICM conferences and workshops. In the long view, solving the problems addressed by CICM is an important milestone in formulating the next generation of mathematical software.

The first CICM was held in Birmingham, UK, in 2008. Although combinations of the constituent meetings had been held together previously, this was the first time this set of conferences and workshops were held together under the CICM name. In some sense this was a symbolic step, recognizing that these areas shared common challenges that should be addressed together. The anchor meetings were the Artificial Intelligence and Symbolic Computation (AISC) conference, the 15th Symposium on the Integration of Symbolic Computation and Mechanized Reasoning (Calculemus 2008) and the 7th International Conference on Mathematical Knowledge Management (MKM 2008). A number of related workshops also joined the meeting.

Those participating in CICM 2008 felt the meeting worked well and wished to hold a federated event again in 2009. The Ontario Research Centre for Computer Algebra (ORCCA) at the University of Western Ontario offered to host the meeting on the shore of Lake Huron in Grand Bend, Ontario. The governing bodies of both Calculemus and MKM agreed to co-locate at CICM 2009. AISC could not participate because it was held only every second year. Two of the workshops of CICM 2008, Mathematical User Interfaces and Towards a Digital Mathematics Library, as well as a number of additional workshops also decided to hold their next event at CICM 2009. Thus, the CICM 2009 meeting included two long-standing international conferences:

- 16th Symposium on the Integration of Symbolic Computation & Mechanized Reasoning (Calculemus 2009)
- 8th International Conference on Mathematical Knowledge Management (MKM 2009)

as well as the following inter-related workshops:

- Second Compact Computer Algebra Workshop (CCA 2009)
- Second Workshop Towards a Digital Mathematics Library (DML 2009)
- W3C Workshop on Ink in Multimodal Applications (InkMMI 2009)
- 4th Mathematical User Interfaces Workshop (MathUI 2009)
- 22nd OpenMath Workshop (OpenMath 2009)
- Third Pen-Based Mathematical Computation (PenMath 2009)

Each of these conferences and workshops had its own successful predecessors, but for each of them it was the first time to be held in North America.

CICM 2009 featured a range of distinguished plenary speakers, representing the interests of the participants. These invited speakers and their hosting events were:

- Rob Arthan (Lemma 1 Ltd and Queen Mary, University of London, UK), “Computational Logic and Continuous Mathematics, Pure and Applied,” *Calculus*.
- Dorothea Blostein (Queen’s University, Canada), “Math-Literate Computers,” MKM and PenMath.
- Jacques Calmet (U. Karlsruhe, Germany), “Abstraction-Based Information Technology: A Framework for Open Mechanized Reasoning,” *Calculus*.
- John Fitch (University of Bath, UK), “CAMAL 40 Years On — Is Small Still Beautiful?” CCA.
- Georges Gonthier (Microsoft Research Cambridge, UK), “Software Engineering for Mathematics,” MKM.
- Patrick Ion (Mathematical Reviews, AMS, USA), “Some Traditional Mathematical Knowledge Management,” MKM and OpenMath.
- Marko Panić (Microsoft Development, Serbia), “Math Handwriting Recognition in Windows 7 and Its Benefits,” MathUI and PenMath.
- David Ruddy (Cornell University, USA), “Assembling the Digital Mathematics Library,” DML.

This volume represents the formal proceedings of CICM 2009. It includes a record of the invited talks and the conference papers accepted for the proceedings. Work presented at the workshops and in-progress work presented at the conferences was made available in informal proceedings.

We now describe in more detail the goals and objectives of the constituent meetings of CICM 2009, and the process by which papers were selected for these proceedings.

16th Symposium on the Integration of Symbolic Computation and Mechanized Reasoning (Calculus 2009)

Calculus is a series of conferences dedicated to the integration of computer algebra systems and systems for mechanized reasoning, interactive theorem provers

or proof assistants and the automated theorem provers. Currently, symbolic computation is divided into several more or less independent branches: traditional ones (e.g., computer algebra and mechanized reasoning) as well as newly emerging ones (on user interfaces, knowledge management, theory exploration, etc.) The main concern of the Calculemus community has been to bring these developments together in order to facilitate the theory, design and implementation of integrated systems for computer mathematics that will routinely be used by mathematicians, computer scientists and engineers in their everyday business. The scope of Calculemus covers all aspects of the interplay of mechanized reasoning and computer algebra, including cross-fertilization between those two research areas, as well as the development of integrated systems that transcend both computer algebra and theorem proving.

Since 1999, to ensure interaction with both the deduction and computer algebra communities, Calculemus has co-located with closely related conferences: Federated Logics Conference 1999 (Trento, Italy), ISSAC 2000 (St. Andrews, UK), IJCAR 2001 (Siena, Italy), AISC 2002 (Marseilles, France), TPHOLS and TABLEAUX 2003 (Rome, Italy), IJCAR 2004 (Cork, Ireland), Formal Methods 2005 (Newcastle upon Tyne, UK), ISSAC 2006 (Genoa, Italy), MKM 2007 (Hagenberg, Austria), and with AISC and MKM within CICM 2008 (Birmingham, UK).

There were 17 full papers submitted to Calculemus 2009. Each of these received at least three reviews, followed by an author response phase. Of these submissions, 10 were accepted for full presentation at the conference and publication in this volume. In addition to these papers, extended abstracts were also solicited to provide a venue for discussion of work in progress. A supplementary proceedings for the work in progress is available at the Calculemus website <http://www.calculemus.net>.

9th International Conference on Mathematical Knowledge Management (MKM 2009)

The Mathematical Knowledge Management conferences arose similarly from common requirements at the boundaries of neighbouring fields. MKM lies at the intersection of mathematics and computer science with the goal of developing effective techniques, based on formal mathematics and software technology, to take advantage of the enormous knowledge available in current mathematical sources and to organize mathematical knowledge in new ways. Dually, due its very nature, the realm of mathematical information is an attractive candidate for testing innovative theoretical and technological solutions for content-based systems, interoperability, management of machine understandable information, and the Semantic Web. This led to a series of conferences spanning the decade, with meetings held in Hagenberg, Austria (2001), Bertinoro, Italy (2003), Białowieża, Poland (2004), Bremen, Germany (2005), Wokingham, UK (2006), Hagenberg, Austria (2007), Birmingham, UK (2008) and Grand Bend, Ontario, Canada (2009).

MKM 2009 solicited research contributions of two forms: longer papers of about 15 pages and short communications. There were 28 long papers and 6 short communications submitted. Each paper received between 2 and 5 anonymous reviews, for a total of 100 reports. Long paper submissions were also considered for the short communication category. In the end, 16 submissions were accepted as long papers and 6 as short communications for these proceedings. In addition, seven more preliminary submissions were accepted for oral presentation and electronic publication.

Second Compact Computer Algebra Workshop (CCA 2009). The art of compact computer algebra is experiencing a resurgence in relevance and importance. New directions for symbolic computing include the migration from workstations to hand-held devices and the changing role from stand-alone applications to lightweight services within integrated systems. Whether running on a graphing calculator or as support of a client-side web application, certain applications of computer algebra require compact data representation, space-efficient algorithms and effective memory management. The purpose of this workshop was to communicate efforts in research, design, development and applications of compact computer algebra.

Second Workshop Towards a Digital Mathematics Library (DML 2009). Mathematicians dream of a digital archive containing all peer-reviewed mathematical literature ever published, properly linked and validated/verified. It is estimated that the entire corpus of mathematical knowledge published over the centuries does not exceed 100,000,000 pages, an amount easily manageable by current information technologies. The workshop's objectives were to formulate the strategy and goals of a global mathematical digital library and to summarize the current successes and failures of ongoing technologies and related projects.

W3C Workshop on Ink in Multimodal Applications (InkMMI 2009). The goal of this workshop was to identify and prioritize requirements for changes, extensions and additions to digital ink standards, especially in multimodal applications developed based on the W3C's MMI Architecture and as a means of making InkML more useful in current and emerging contexts.

4th Mathematical User Interfaces Workshop (MathUI 2009). This workshop was intended to bring together researchers working on MKM but from the perspective of mathematics manipulated by end users. Accordingly, an emphasis was on providing users with interfaces and software systems that enhance their mathematical working experience. The topics of the workshop centered around presentation and manipulations of mathematical knowledge, workflows induced by mathematical knowledge representations, human communication of mathematical content, user studies with MKM tools or other mathematical interfaces and other novel interfaces to mathematics software.

22nd OpenMath (OpenMath 2009). With the development of MathML 3, OpenMath entered a new phase of its evolution. Topics to be discussed at the

workshop included convergence of OpenMath and MathML 3, reasoning with OpenMath, software using or processing OpenMath, as well as new OpenMath Content Dictionaries.

Third Pen-Based Mathematical Computation (PenMath 2009). The use of the pen to enter, edit, and manipulate mathematical expressions can lead to a qualitative improvement in the ease of use of mathematical software. The purpose of this workshop was to explore this area, including pen-based mathematical interfaces for computer algebra and document processing, expression entry editing and manipulation, data collection and analysis, structural analysis, semantic methods, on-line and off-line mathematical handwriting recognition and to receive reports on implementations and experiments. The first workshop in this series was held as a special session of the 2005 Applications of Computer Algebra conference in Nara, Japan, and the second workshop was held as a special session of the conference Communicating Mathematics in the Digital Era conference in Aveiro, Portugal.

Numerous people contributed to making CIBM 2009 happen. A list of organizers is to be found on the following pages. We thank them for their very substantial collective effort. To make the meeting as accessible as possible, a number of organizations were approached for financial contributions. We are most grateful for the generosity of the Fields Institute for Research in Mathematical Sciences, our principal sponsor. We also wish to thank McMaster University, the University of Waterloo, the University of Western Ontario (Faculty of Science and Research Western), Wilfrid Laurier University and Maplesoft for financial support. We thank the Ontario Research Centre for Computer Algebra and its members for their assistance and ACM SIGSAM for recommending *in cooperation* status for CIBM 2009.

We are at a special point in the development of mathematical software, where systems in each of their individual niches have grown extremely powerful. In continuing to expand their capabilities, they have invariably reached the boundaries of their domains of origin and have started expanding into adjoining areas. A clear understanding of what should happen at these boundaries is essential to lay the foundation for future generations of versatile, integrated and intelligent systems for mathematics. It has been our hope that the discussions at CIBM are a fruitful step in this direction.

April 2009

Jacques Carette
Lucas Dixon
Claudio Sacerdoti Coen
Stephen M. Watt

Organization

CICM has an Organizing Committee and the constituent events have their own Program Committees. The CICM Organizing Committee comprises the local organizers, the Program Committee Chairs of the constituent meetings, and past organizers as advisors.

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